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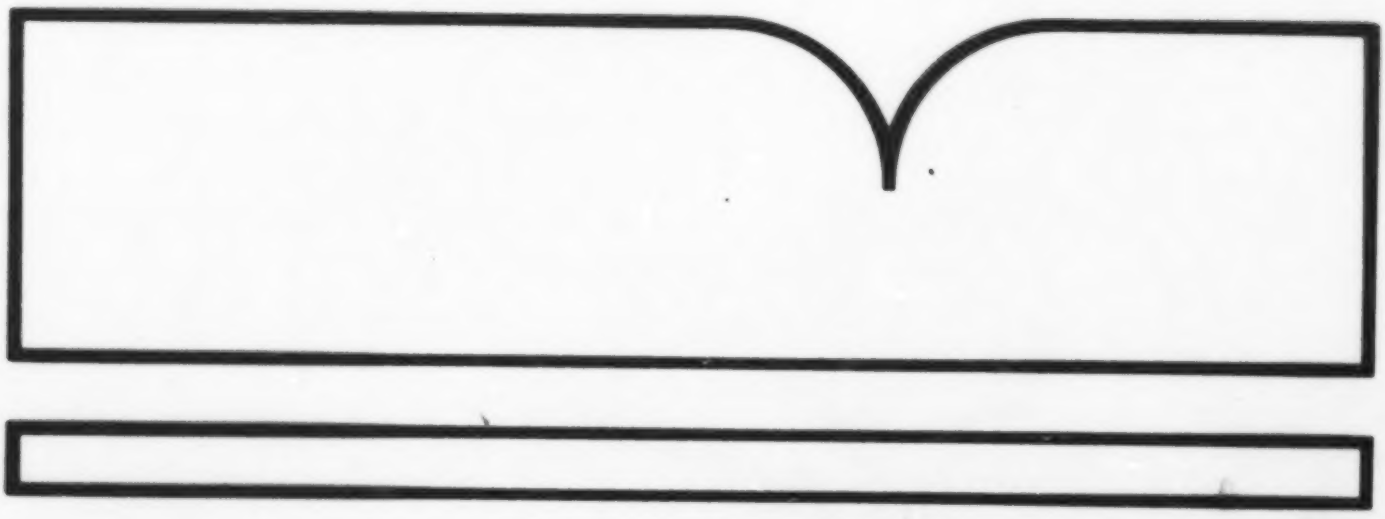

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THE INTERNATIONAL SULFUR DEPOSITION MODEL EVALUATION

by

Terry L. Clark and Robin L. Dennis
Atmospheric Sciences Research Laboratory
Research Triangle Park, NC 27711

Steve Seilkop
Program Resources, Inc.
Research Triangle Park, NC 27709

Eva C. Voldner and Marvin P. Olson
Atmospheric Environment Service
Environment Canada
Downsview, Ontario M3H 5T4

and

Mayer Alvo
University of Ottawa
Ottawa, Ontario

ATMOSPHERIC SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT

Eleven long-term sulfur deposition models are evaluated for each season of 1980 using screened precipitation chemistry data from five North American networks. Two objectives of the model evaluation are 1) to identify which models best replicate the observed temporal and spatial patterns of sulfur wet depostion within data uncertainty limits (i.e., from measurement errors and spatial variability) and 2) to delineate for each model areas and periods of good and poor agreement with observations. Analyses indicated that the MOE, SERTAD and TVA models significantly under/overpredict in neither more than 20% of the evaluation region for any season nor in 25% of any of the four subregions. Many of the models replicated rather well the temporal pattern. However, the temporal patterns of the SIMPMOD and STATMOD models were significantly different.

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Terry L. Clark* and Robin L. Dennis*
Atmospheric Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Eva C. Voldner and Marvin P. Olson
Atmospheric Environment Service
Environment Canada
Downsview, Ontario M3H 5T4

Steve Seilkop
Program Resources, Inc.
Research Triangle Park, NC 27709

Mayer Alvo
University of Ottawa
Ottawa, Ontario

1. INTRODUCTION

Eleven long-term sulfur deposition models (Table 1) were evaluated for each season of 1980. The selection of the model evaluation year was based on two criteria: (1) the availability of detailed U.S. and Canadian SO_2 emission inventories for the specific evaluation year and (2) the availability of an appropriate sulfur wet deposition data base to determine spatial patterns across a large part of North America for each season. The evaluation was limited to sulfur wet deposition since sufficient measurements of air concentrations and sulfur dry deposition amounts were not available.

A standardized model input data base for 1980 was compiled and distributed to the participating modelers (Clark et al., 1985). The modelers in turn submitted predictions of seasonal and annual air concentrations and both wet and dry depostions of SO_2 and sulfate or total sulfur at 41 to 66 designated sites (Figure 1). The validation data base consisted of amounts of sulfur wet deposition calculated from screened precipitation chemistry measurements (Voldner et al., 1984) obtained from EPA's Acid Deposition System (ADS) data base (Watson and Olsen, 1984). Two of the objectives of the model evaluation were to

(1) Identify which models best replicate the observed temporal and spatial patterns of sulfur wet deposition within data uncertainty limits (i.e., measurement errors and spatial variability) and

(2) Delineate for each model, areas and periods of good and poor agreement with the observed sulfur wet deposition amounts.

Several aspects of the International Sulfur Deposition Model Evaluation (ISDME) results are summarized for each of these objectives.

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* On assignment from the National Oceanic and Atmospheric Administration, U. S. Department of Commerce.

Table 1. The eleven regional models evaluated in the ISDME.

Statistical Models	
SERTAD	Model for Statistical Estimates of Regional Transport and Acidic Deposition
STATM3D, SIMPM3D	Environmental Research & Technology Inc. Statistical Model and a simpler version
TVA	Tennessee Valley Authority Model I
Deterministic Models	
AES	Atmospheric Environment Service Long-Range Transport Model
ASTRAP	Advanced Statistical Trajectory Regional Air Pollution Model
MOE	Ontario Ministry of the Environment Long-Range Transport Model
RELMAP	Regional Lagrangian Model of Air Pollution (formerly ENAMAP-2)
RIVAD	Regional Impacts on Visibility and Acid Deposition Model
RTM-II	Regional Transport Model
UMACID	University of Michigan Atmospheric Contributions to Interregional Deposition Model

2. SUMMARY OF ISDME RESULTS

2.1 Temporal Patterns

Analyses of the 1980 precipitation chemistry data demonstrate that sulfur wet deposition has a strong seasonal dependence. These seasonal variations, or the temporal patterns, were predicted by the models at 30 sites and compared to the observed temporal pattern determined from the mean seasonal observations at the same sites. The winter season consisted of January, February and March and so on. These sites, designated by the large dots in Figure 1, were selected on the basis of (1) the measurements passing the screening criteria for every season and (2) the availablity of predictions from every model.

Figure 2 illustrates the mean percentage of the 1980 annual sulfur wet deposition observed and predicted during each season. The seasonal pattern of the observations indicates that approximately 70% of the annual amount of sulfur wet deposition occurs in the spring and summer. The winter and autumn amounts account for approximately 15% each.

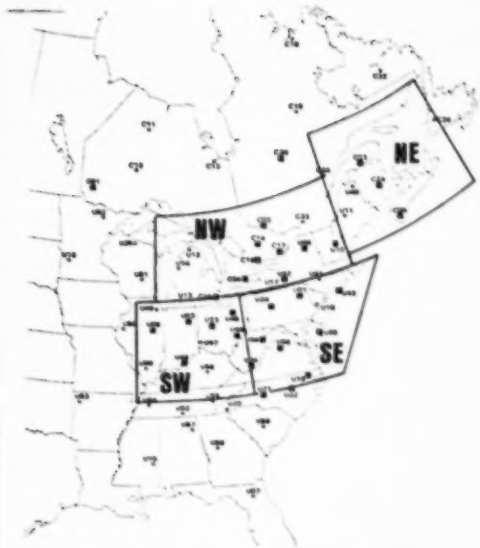

Figure 1. The 66 ISDME sites where 1980 seasonal predictions of sulfur wet deposition were available. Both predictions and observations were available for each season at the 30 sites denoted by the larger dots.

Several models poorly replicate the observed seasonal pattern. SIMPMOD winter predictions account for nearly a third of its annual prediction, more than double the observed winter contribution. Meanwhile, STATMOD's pattern is virtually flat with the contribution of each season being nearly equal. The patterns of the remaining models are more similar to the observed pattern.

2.2 Seasonal Spatial Patterns

The ISDME evaluation assessed the ability of the models to replicate the observed seasonal spatial patterns. For each season, spatial patterns of the observations and predictions were defined via an interpolation technique known as simple kriging (Finkelstein, 1984). This method provided estimates of uncertainties at each of the half-degree grid cells of eastern North America. These uncertainty estimates pertained to both interpolation and measurement errors.

In each of the four subregions depicted in Figure 1, pairs of interpolated seasonal observations (Y_o) and predictions (Y_p) are compared at each half-degree grid cell. A difference between the two is declared to be significant at approximately the 95% confidence level when it exceeds the uncertainty limit of the interpolation,

$$\pm 2 \left[\mathrm{Var}\,(Y_o) + \mathrm{Var}\,(Y_p) \right]^{1/2}$$

where the terms represent the kriging variance estimates. The percentage of cells in each subregion and the composite of the four subregions where significant differences occur are provided in Table 2.

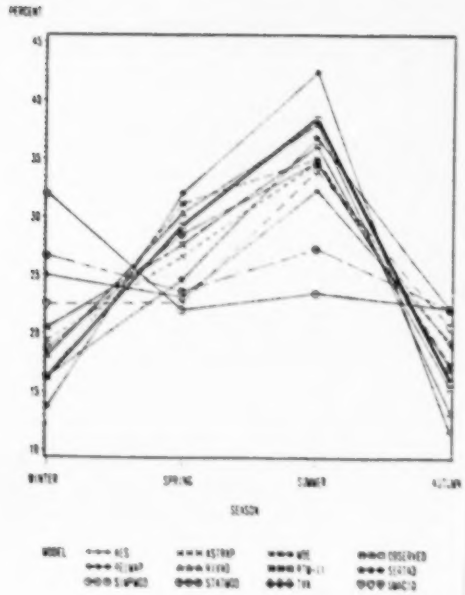

Figure 2. The 1980 temporal patterns of observed and predicted amounts of sulfur wet deposition.

These percentages and other measures are used in the ISDME to distinguish the performance of one group of models from that of the others. Here, significant differences in less than 20% of the composite region for all seasons and in less than 25% of any subregion for any season distinguish one group of models from the others.

The seasonal results in Table 2, ordered by the relative magnitude of the observed seasonal contributions to the annual total of sulfur wet deposition, indicate that only MOE, SERTAD and TVA do not under/overpredict in more than 20% of the composite region for all seasons and in more than 25% of any subregion for any season. In spring, none of the predictions of these models are different from the observations. MOE tends to underpredict for all other seasons, SERTAD tends to overpredict in autumn and winter, and TVA tends to underpredict in summer and overpredict in winter.

The predictions from the other eight models differ from the observations across a greater percentage (> 20%) of the composite region for two or three seasons, and/or across a large portion (> 25%) of at least one subregion. Two of these models perform best for two seasons. AES predictions for summer and spring differ across less than 10% of the composite area, yet this model overpredicts across much of the southeastern subregion in the other two seasons. Just the opposite, UMACID predictions for autumn and winter differ across less than 3% of the total area, while the model underpredicts across more than 25% of the northeastern subregion in summer and more than 25% of the southwestern subregion in summer and spring.

Table 2. Percent of subregions (depicted in Figure 1) where differences between predicted and observed amounts of sulfur wet deposition are significant. The signs following the percentages indicate the predominance of underpredictions (-) and overpredictions (+).

	Summer 1980					Spring 1980				
	NW	NE	SE	SW	ALL	NW	NE	SE	SW	ALL
AES	4-	17-	4+	15-	9-	1-	0	0	0	1-
ASTRAP	6+	1-	49+	5+	11+	2+	0	20+	0	4+
MOE	10-	18-	3-	17-	12-	0	0	0	0	0
RELMAP	6+	8-	90+	33+	24+	1+	0	60+	14+	12+
RIVAD	43-	26-	27-	47-	37-	16-	0	26-	58-	22-
RTM-II	48-	23-	26-	47-	39-	39-	1-	28-	64-	33-
SERTAD	3+	1-	4+	4-	3	0	0	0	0	0
SIMPMOD	39-	29-	3+	31-	30-	0	0	0	0	0
STATMOD	55-	38-	11-	30-	39-	33-	2-	0	2-	14-
TVA	16-	22-	2+	11-	15-	0	0	0	0	0
UMACID	16-	27-	1+	31-	20-	13-	2-	3-	32-	13-

	Autumn 1980					Winter 1980				
	NW	NE	SE	SW	ALL	NW	NE	SE	SW	ALL
AES	10+	2+	64+	0	13+	1+	0	86+	41+	21+
ASTRAP	15+	2+	54+	11+	16+	12+	0	53+	29+	18+
MOE	0	10-	0	0	2-	0	1-	5-	0	1-
RELMAP	4-	0	8+	0	3+	5-	0	51+	5+	10+
RIVAD	24-	21-	0	0	15-	31-	1-	0	4-	14-
RTM-II	19-	0	0	0	8-	28-	0	0	3-	12-
SERTAD	14+	11+	14+	0	10+	1+	0	20+	0	3+
SIMPMOD	3+	0	79+	18+	16+	15+	0	97+	62+	33+
STATMOD	1-	0	15+	0	2+	3-	0	33+	33+	12+
TVA	0	13-	11+	3+	5	0	0	13+	4+	3+
UMACID	0	0	3+	0	1+	1-	0	9+	2+	2+

Both ASTRAP and SIMPMOD perform best in spring. In no subregion does the latter model under/overpredict for this season. ASTRAP tends to overpredict across approximately 50% of the southeastern subregion for each of the other three seasons.

The remaining four models, RELMAP, RIVAD, RTM-II and STATMOD, perform best in autumn. Both RIVAD and RTM-II tend to underpredict for each season, especially for the western two subregions in summer and spring. As illustrated by Figure 2, STATMOD tends to overpredict in winter and underpredict in summer and spring. RELMAP overpredicts across a large portion (> 50%) of the southeastern subregion for the other three seasons.

As a consequence of their dependency on the spatial variability of both observations and predictions, the uncertainty limits can vary substantially for some models. The percentage of cells where the predictions significantly differed from the observations would decrease for increasing spatial variability in the predictions. Since the spatial variability was relatively high for ASTRAP predictions and RELMAP predictions for summer and spring, the percentages for these models are expected to be somewhat greater than those in Table 2.

3. CONCLUSIONS

Only a few aspects of the results of the International Sulfur Deposition Model Evaluation are presented here. As will be discussed in the ISDME final report, available in January 1987, additional measures should be used to properly assess the performance of the eleven models (e.g., spatial correlation, bias, centroids, orientation of the major axis, location and magnitude of maxima, etc.).

From the results presented here, it is evident that two of the eleven models do not replicate well the observed temporal pattern. STATMOD mean seasonal predictions of sulfur wet deposition are independent of the season, which contradicts the temporal pattern of the observations (i.e., approximately 40% of the annual total occurring in summer, 30% in spring, and 15% each in autumn and winter). SIMPMOD exhibits similar behavior, but its mean winter predictions, expressed as a percentage of the annual predictions, are approximately twice those observed.

Comparisons of seasonal spatial patterns, generated via simple kriging with consideration of the uncertainties of the observations, indicate that the eleven models could be classified into two groups. The first group of models (i.e., MOE, SERTAD and TVA) neither significantly under/overpredict at approximately the 95% confidence level across more than 20% of the evaluation region of eastern North America nor more than 25% of any of the four subregions. The relatively good performance of SERTAD, however, is overshadowed by the fact that (1) its predictions of sulfate air concentrations are much greater than both those of other models and available measurements (apparently a consequence of its high transformation rates near the sources and its assumption that sulfate dry deposition can be ignored) and (2) a high background contribution to sulfur wet deposition is added.

The second group of eight models significantly under/overpredict across more than 20% of the evaluation region and/or more than 25% of any of the four subregions for two seasons (AES and UMACID) or three seasons (ASTRAP, RELMAP, RIVAD, RTM-II, SIMPMOD and STATMOD).

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